Mirror objects in the solar system?

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This talk was given at the Tunguska-2001 international conference but it is not about the Tunguska event. Instead we tried to give some flavor of mirror matter, which is predicted to exist if parity is an unbroken symmetry of nature, to non-experts. The possible connection of the mirror matter ideas to the Tunguska phenomenon was indicated by Foot and Gninenko some time ago and was elaborated by Foot in the separate talk at this conference. If the mirror world interpretation of the Tunguska like events is indeed correct then the most fascinating (but very speculative) possibility is that some well known celestial bodies with strange properties are in fact made mostly from mirror matter, and so maybe the mirror world was discovered long ago and we just have not suspected this!

This conference is devoted to the 1908 Tunguska mysterious event. Human beings like mystery stories very much. Maybe the greatest mystery being our very ability to be so curious. It seems that the strange aspiration for unraveling mysteries and even stranger belief that the truth really exists for every case is hardwired in our brains. This passion for knowledge is powerful enough to compete with other human passions and makes possible the existence of substantial science despite the fact that scientists, just like other human beings, are subject to various human weaknesses not compatible with genuine science like arrogance, vanity and unfairness.

It is not easy to find the truth about the event so old and so enigmatic. Thus it is not surprising that numerous hypotheses were suggested for explanation to what happened in the Central Siberia near the Podkamennaya Tunguska River in the early morning hours of June 30, 1908 [1]. A new hypothesis is considered in Foot's talk at this conference [2] according to which Tungus tribesmen and Russian fur traders had witnessed an atmospheric explosion of some mirror meteoroid. What is mirror meteoroid? It is a meteoroid made from the mirror matter. And what follows is an attempt to explain to you the meaning of words "mirror matter". While describing certainly exotic things, we will try to follow the advice "Be open-minded, but not so open-minded that your brains fall out."

The main motivation for the mirror-world comes from the symmetry argument: the existence of mirror matter makes the world left-right symmetric. What is left and what is right at the fundamental, that is quark and lepton level, needs some explanation. You know that many physical quantities are vectors, like velocity or acceleration. The main characteristic property of vectors is their transformation law under rotations. For example, if one rotates a radius-vector $\vec{r} = (x, y, z)$ by the angle θ around the z-axis its x- and y-coordinates will change according to

$$
\begin{aligned}
x' &= \cos\theta \; x + \sin\theta \; y \\
y' &= -\sin\theta \; x + \cos\theta \; y
\end{aligned}
\tag{1}
$$

Any other vector also transforms like this. Now the transformation law above shows that a vector remains unchanged under 360°-rotation. Therefore vectors can not be the most fundamental objects because the 360°-rotation is not an identity transformation and the most fundamental objects are expected to change under such rotations. The last assertion does look strange, does it not? Why a 360°-rotation is not an identity transformation? In fact it is, but only for isolated objects. In general something changes in this world when somebody makes a full turn on his heels. Our ancestors intuitively always understood this. In fairy stories one can find quite often an assertion like this: "The magician turned around on his heels and turned into a mouse." If you do not believe in fairy stories maybe the following demonstration by Dirac [3] will be more convincing for you. Take a triangle made from some hard material (Dirac himself used a pair of scissors) and attach elastic strings to its vertexes. Fix other ends of the strings, for example as shown in the figure below
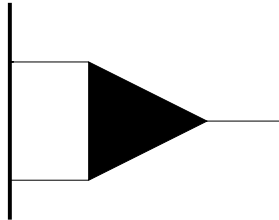
Use the sole string as the rotation axis and turn the triangle around it by one full turn. The other two strings will become twisted. Now keep the triangle fixed and try to remove the twist by manipulating the elastic strings. You failed to achieve this? Not surprising because it can be proved [4] that it is impossible. But more surprises are waiting to you. Go ahead and turn again the triangle by one full turn in the same direction. The strings will become twice more twisted as the triangle has made two full turns. However this time it is possible to untwist strings by taking them over and around the fixed triangle. This fact demonstrates clearly that only the 720°-rotation and not the 360°-rotation is the identity transformation. But to really believe this you should perform the above described exercise by yourself.

Actually there is another way to demonstrate the distinction between 360°- and 720°-rotations. For this demonstration you do not need to prepare any equipment at all except a cup of coffee. It turns out that our arms are properly designed for the trick which demonstrates the distinction between 360°- and 720°-rotations. The trick was invented by Balinese candle-dancers long ago and performed countless times without realizing any deep mathematics behind it. In presence of the more scientifically trained audience the trick was firstly performed by Feynman during his 1986 Dirac memorial lecture [5]. Now you can try this Balinese candle-dance trick by yourself using the following instructions given by Burton [6]: "You hold the coffee cup with your right hand underneath it, straight out in front of you. Now bring it left, under your underarm, awkwardly around front with your elbow straight up in the air. That's 360 degrees, and you're a pretzel. Keep going around counterclockwise, this time swinging your arm around over your head. At 720 degrees the coffee cup is back where it started, unspilled, and your arm is straight once more. Keep going round and round until you believe it."

The trick even has a technical application. According to Hansen [3], in 1971 D. A. Adams patented in USA a solution to the problem of transferring electrical current to a rotating plate without the wires being entangled based on the Balinese candle-dance trick. For another interesting application of a Balinese candle dance, at 7200 revolutions per minute, in a medical centrifuge see Burton's story [6]. Let us also indicate some other literature sources [7] where you can find further discussion of 360°-rotations.

To find more fundamental objects behind vectors let us note that from a vector one

can make 2×2 traceless matrix by using Pauli matrices. For example, the radius-vector is associated with the matrix

$$X = x\sigma_1 + y\sigma_2 + z\sigma_3 = \begin{pmatrix} z & x - iy \\ x + iy & -z \end{pmatrix}.$$

Under rotations (1) the matrix X transforms like this

$$X' = UXU^+, \tag{2}$$

where

$$U = e^{i\sigma_3 \frac{\theta}{2}} = \begin{pmatrix} e^{\frac{i\theta}{2}} & 0 \\ 0 & e^{-\frac{i\theta}{2}} \end{pmatrix}. \tag{3}$$

Note that the transformation matrix U depends now on $\frac{\theta}{2}$ and thus changes sign under 360°-rotation! Let us decompose the matrix X into simpler building blocks:

$$X = \xi\xi^T C = \begin{pmatrix} \xi_1 \\ \xi_2 \end{pmatrix} \begin{pmatrix} \xi_1 & \xi_2 \end{pmatrix} \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix} = \begin{pmatrix} -\xi_1\xi_2 & \xi_1^2 \\ -\xi_2^2 & \xi_1\xi_2 \end{pmatrix}, \tag{4}$$

where ξ is an object with 2 complex components

$$\xi = \begin{pmatrix} \xi_1 \\ \xi_2 \end{pmatrix}$$

and the presence of the "charge conjugation matrix" $C = i\sigma_2$ is necessary to make the r.h.s. of (4) traceless (by this condition the constant matrix C is determined uniquely up to normalization). Because $C\sigma_3^+ = -\sigma_3^T C$ we will have $CU^+ = U^T C$ and

$$X' = U\xi\xi^T CU^+ = U\xi\xi^T U^T C = (U\xi)(U\xi)^T C.$$

Therefore the transformation law for the object ξ is

$$\xi' = U\xi \tag{5}$$

and this object changes sign under 360°-rotations. Such objects, some kind of square root of vectors, are called spinors. And quarks and leptons are spinors. One can think that this sign change under 360°-rotations should be irrelevant. Especially if you remember that wave function phase does not matter in quantum mechanics. Indeed a 360°-rotation does not matter for *isolated* spinor. But if this spinor is a part of a bigger system this minus sign matters a lot: it leads to the Pauli exclusive principle [5, 6]. Hence all the chemistry and our very existence are based on this minus sign!

Now it is time to ask how the spinors transform under Lorentz transformations. Equation (5) suggests the following general transformation law for spinors

$$\xi' = \exp\left\{i\sum_{i=3}^{3}(\mathbf{J_i}\theta_i + \mathbf{K_i}\varphi_i)\right\}\xi,$$

where $\mathbf{J_i} = \frac{1}{2}\sigma_i$ are generators of spatial rotations and $\mathbf{K_i}$ are Lorentz boost generators. The boost is characterized by the parameters φ_i. For example, for the Lorentz boost along x-direction one has

$$\begin{aligned} x^{0\prime} &= \cosh\varphi \ x^0 + \sinh\varphi \ x \\ x' &= \sinh\varphi \ x^0 + \cosh\varphi \ x \end{aligned} \tag{6}$$

where $\cosh\varphi = \gamma$ determines the γ-factor of the boost. Formulas like (1) and (6) in fact determine explicit forms of $\mathbf{J_i}$ and $\mathbf{K_i}$ generators for 4-vectors and hence their commutators. It turns out [8] that the commutation relations can be written in the form

$$[\mathbf{A_i^{\pm}}, \mathbf{A_j^{\pm}}] = i\epsilon_{ijk}\mathbf{A_k^{\pm}}, \quad [\mathbf{A_i^+}, \mathbf{A_j^-}] = 0, \tag{7}$$

where $\mathbf{A_i^{\pm}} = \frac{1}{2}(\mathbf{J_i} \pm i\mathbf{K_i})$. These commutation relations show that the Lorentz group is locally identical to the $SU(2) \times SU(2)$ group. Therefore its representations are labeled by two angular momenta j_- and j_+. All such (j_-, j_+) representations can be constructed from the two fundamental spinor representations $(\frac{1}{2}, 0)$ and $(0, \frac{1}{2})$. Therefore we have two kinds of spinors. The left spinor $(\frac{1}{2}, 0)$ transforms non-trivially under the left $SU(2)$ formed by the $\mathbf{A_i^-}$ generators while remaining unchanged under the right $SU(2)$ formed by the $\mathbf{A_i^+}$ generators. For the right spinor $(0, \frac{1}{2})$ roles of the left and right $SU(2)$ factors of the Lorentz group are interchanged. Left spinor is annihilated by the $\mathbf{A_i^+} = \frac{1}{2}(\mathbf{J_i} + i\mathbf{K_i})$ generators. Therefore for such spinor $\mathbf{K_i} = i\mathbf{J_i} = \frac{i}{2}\sigma_i$, because $\mathbf{J_i} = \frac{1}{2}\sigma_i$ for spinor representation. Analogously for right spinor $\mathbf{K_i} = -\frac{i}{2}\sigma_i$. Thus under Lorentz boosts left spinor ξ_L and right spinor ξ_R transform as

$$\xi_L' = e^{-\frac{1}{2}\vec{\sigma}\cdot\vec{\varphi}}\xi_L, \quad \xi_R' = e^{\frac{1}{2}\vec{\sigma}\cdot\vec{\varphi}}\xi_R. \tag{8}$$

It turns out [8] that for massless spinors the projection of their spin on their momentum direction is negative for left spinors and positive for right spinors. So we can think about left and right spinors as some analogs of left-handed and right-handed screws.

Let $\mathbf{P}$ be space inversion (or parity) operator

$$\mathbf{P}: \quad (x_0, x, y, z) \rightarrow (x_0, -x, -y, -z). \tag{9}$$

How do spinors transform under parity? Inspecting 4-vector transformation laws under Lorentz boosts (6) and under parity (9) one can find that $\mathbf{P}$ anticommutes with the boost generators $\mathbf{K_i}$. But then it is impossible to realize the parity operator by a 2×2 matrix in the ξ_L or ξ_R space because no 2×2 matrix anticommutes with all Pauli matrices. The analogy with screws hints a rescue. Under space inversion left-handed screw goes into right-handed screw and vice versa. Therefore the parity operator should transform left spinors into right spinors and vice versa. Hence to have a spinor realization of the Lorentz group extended by parity one should unify ξ_L and ξ_R spinors into a one 4-component object (Dirac spinor)

$$\psi = \left(\begin{array}{c} \xi_R \\ \xi_L \end{array} \right).$$

Then in the space spanned by ψ spinors there is enough room to realize both Lorentz boost generators $\mathbf{K_i}$ and the parity operator $\mathbf{P}$:

$$\mathbf{K_i} = \left(\begin{array}{cc} -\frac{i}{2}\sigma_i & 0 \\ 0 & \frac{i}{2}\sigma_i \end{array} \right), \quad \mathbf{P} = \left(\begin{array}{cc} 0 & 1 \\ 1 & 0 \end{array} \right), \quad \mathbf{K_i}\mathbf{P} = -\mathbf{P}\mathbf{K_i}.$$

A bit more information about the fundamental nature of left and right spinors and we will be ready to discuss their connection to the mirror matter idea. Using

$$\cosh\frac{\varphi}{2} = \sqrt{\frac{1+\gamma}{2}}, \quad \sinh\frac{\varphi}{2} = \sqrt{\frac{\gamma-1}{2}}, \quad \gamma = \frac{E}{m}$$

we get

$$e^{\frac{1}{2}\vec{\sigma}\cdot\vec{\varphi}} = \cosh\frac{\varphi}{2} + \frac{\vec{\sigma}\cdot\vec{p}}{|\vec{p}|}\sinh\frac{\varphi}{2} = \frac{E+m+\vec{\sigma}\cdot\vec{p}}{\sqrt{2m(E+m)}}.$$

Therefore equations (8) indicate

$$\xi_R(p) = \frac{E + m + \vec{\sigma} \cdot \vec{p}}{\sqrt{2m(E+m)}} \, \xi_R(0), \quad \xi_L(p) = \frac{E + m - \vec{\sigma} \cdot \vec{p}}{\sqrt{2m(E+m)}} \, \xi_L(0), \tag{10}$$

where $\xi_R(0)$ and $\xi_L(0)$ are rest-frame spinors. But you can not tell whether a screw is left-handed or right-handed if the direction the screw points is unknown. So for the rest frame spinors it should be impossible to distinguish left spinors from right spinors and one should have [8, 9]

$$\xi_R(0) = \xi_L(0). \tag{11}$$

Taking this into account allows to rewrite (10) as

$$(E - \vec{\sigma} \cdot \vec{p}) \, \xi_R(p) = m\xi_L(p), \quad (E + \vec{\sigma} \cdot \vec{p}) \, \xi_L(p) = m\xi_R(p).$$

But this is nothing but the Dirac equation for the Dirac spinor ψ

$$(\hat{p} - m)\psi = 0,$$

where the Dirac matrices are given in the chiral representation

$$\gamma_0 = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad \gamma_i = \begin{pmatrix} 0 & -\sigma_i \\ \sigma_i & 0 \end{pmatrix}.$$

You surely know about the central role the Dirac equation plays in our understanding of Nature. And we have just discovered that the Dirac equation is merely assertion that for the spinor particle at rest one can not tell whether it is left-handed or right-handed!

We hope you are convinced now about the fundamental nature of left and right at the quark and lepton level. Moreover, the difference between them should be completely conventional because we arbitrarily had called left to the one $SU(2)$ factor of the Lorentz group and right to the another $SU(2)$ factor. So one expects the world to be left-right symmetric. Parity interchanges left and right. Therefore parity invariance of the world is also expected. But we know that the weak interactions are not parity invariant and the world reflected in a mirror looks different from the original: the **P**-mirror image of the left-handed neutrino is right-handed neutrino which is not observed experimentally.

But this absence of right-handed neutrino not yet indicates left-right asymmetry of the world. It is certainly true that under space inversion left and right becomes interchanged. But in presence of some internal symmetry, when there are several equivalent left-handed states and several equivalent right-handed states, it is not obvious at all what right-handed state should correspond to a given left-handed state. A priori all operators of the type **PS**, where **P** is the (naive) parity operator considered above and **S** is some internal symmetry operator, are equally good to represent space inversion. Usually internal symmetry **S** is broken. But the parity symmetry **P** is also broken as we have seen above. So it may happen that **PS** remains unbroken nevertheless and therefore it can be served as representing the equivalence between left and right. What remains is to find a good enough internal symmetry **S**. And the charge conjugation **C**, that is the symmetry between particles and anti-particles, is an obvious candidate [10]. Indeed the world looks symmetric when reflected in the **CP**-mirror because under **CP** left-handed neutrino goes into right-handed antineutrino and vice versa.

But **CP** invariance is also broken as experiments in the neutral kaon system had shown. Recent experiments in the neutral B-meson system also indicate that our world is not **CP**-symmetric and therefore it is either left-right asymmetric or **CP** does not represent the symmetry between left and right. Most of the scientific community accepted the first possibility of the left-right asymmetric world after the remarkable discovery of **CP** violation in

K-meson decays. This viewpoint remains dominant today. But it is not necessarily correct. Nineteenth century humorist Josh Billings warned long ago [11] "The trouble with most folks isn't so much their ignorance. It's know'n so many things that ain't so." Evolution of physics is a subtle interplay between theory and experiment governed by Lee's two laws [12]. The rigidity of accepted opinions in physics is well explained by the first law which says "Without experimentalists, theorists tend to drift." So one needs breakthrough experiments to change an orthodox view of the world. The experimental discovery of the **CP** violation in K-meson decays was one such breakthrough experiment which changed the previous beliefs by a new orthodoxy that only the proper Poincaré symmetries are symmetries of Nature and that the improper Poincaré symmetries, like space inversion and time reversal, are violated. But "Without theorists, experimentalists tend to falter" according to the Lee's second law of physicists. Lee himself provides [12] a classical example to illustrate this second law. During two decades a dozen of experiments were performed to measure the Michel parameter ρ in μ-decay. Never the new experimental value lied outside the error bars of the preceding one. Nevertheless conclusions about the nature of weak interactions changed dramatically: the first experiments indicated $\rho = 0$ while the final value was $\rho = 3/4$, and the experiments converged to this final value only after the theoretical prediction. Of course nobody doubts that **CP** and **P** violations are firmly established experimentally. But, opposite to the common belief, this fact does not necessarily means that Nature is left-right asymmetric. The theoretical idea which rescues left-right symmetry was put forward by Lee and Yang [13] and involves a dramatic duplication of the world. For any ordinary particle the existence of the corresponding "mirror" particle is postulated. These mirror particles are sterile with respect to the ordinary gauge interactions but interact with their own set of mirror gauge particles. Vice versa, ordinary particles are singlets with respect to the mirror gauge group which is an exact copy of the Standard Model $G_{WS} = SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ group with only difference that left and right are interchanged. Hence the mirror weak interactions reveal an opposite **P**-asymmetry so that **MP**, where the internal symmetry operator **M** interchanges ordinary and mirror particles, remains unbroken. The world so extended will look symmetric when reflected in the **MP**-mirror.

Therefore the desired invariance of the world with regard to the space inversion operation (and other improper Poincaré symmetries), combined with the experimental fact that **P** and **CP** are broken in our world, provides strong motivation for the mirror matter idea. One can even imagine a reason why gauge and matter contents of our world is duplicated. It may happen that the low energy world we are familiar with looks quite different from the world at high energies. Recently more and more popularity gains the Brane World idea [14]. According to this idea our low energy world is located on some 3-dimensional wall (a brane) in higher dimensional space. More precisely, only the gauge and matter particles are located on the brane. Gravity, in contrast, propagates into a full bulk and so is essentially high dimensional. But this high dimensionality of gravity is hidden at distances large compared to the size of extra dimensions. The localization of particles on the brane is not absolute: it takes place only at low energies. When energies are high enough compared to some characteristic scale the localization, as well as the brane, disappears and the world restores its high-dimensional nature for all degrees of freedom. A good illustration of the Brane World idea is M. C. Escher's lithograph "Liberation" shown in Fig.1.

Now suppose that the particles can not penetrate (for low energies) the thick enough brane and so are localized on one of its surface. Particles trapped on the another surface of the brane will appear as some kind of dark matter for us because objects located on different brane surfaces are connected only by gravity, which can penetrate the brane. The parity invariance of such world could be restored if the parity transformation involves a transition from one brane surface to another. Therefore the mirror particles could be just particles located on the another surface of our brane. It is even possible to imagine the mirror world

Fig. 1. The Brane World idea illustrated by M. C. Escher's lithograph "Liberation".

without mirror particles if our brane is some analog of one-sided closed surface. In [22] this idea was illustrated by M. C. Escher's woodcut "Möbius Strip II". Such Möbius world could be locally left-right asymmetric but nevertheless globally symmetric. For example, suppose a 2-dimensional Möbius world is inhabited by some creatures all having their hearts on left side. So the symmetry between left and right is violated at least on creatures level. But inspecting the things closer the creatures will find that this violation of symmetry is only apparent as there are some shadow mirror creatures around which have their hearts on right side. But this mirror creatures are difficult to discover because they reveal themselves only trough gravity. So scientists from this 2-dimensional world will need a mirror world to describe physics around them. From our 3-dimensional perspective, however, it is quite evident that there is no global difference between "ordinary" and "mirror" creatures.

We hope your are convinced now that the mirror world idea has good theoretical motivation and is not so exotic as it may appear. Maybe some historical remarks would be

appropriate here. As we had already remarked the original idea dates back to Lee and Yang's seminal 1956 paper [13]. But, in contrast to the main conclusion of this paper that our world could be parity non-invariant, the mirror world way of restoring the symmetry between left and right had virtually no impact on contemporary science for a long time. For our best knowledge, for the first time the mirror world idea was taken seriously and investigated by Kobzarev, Okun and Pomeranchuk in 1966 paper [15]. Note by the way that the nickname "mirror world" was firstly coined in this very work. Nevertheless the idea remained unknown for the majority of researchers as witnessed by the fact that it has been rediscovered at least two times [16, 17]. But there was a small group of physicists which knew about the idea and tried to elaborate it. For example, the astrophysical consequences of the idea were thoroughly investigated by Blinnikov and Khlopov [18]. Recently the idea became somewhat more popular after in two 1995 papers by Foot and Volkas [19], Berezhiani and Mohapatra [20] it was noticed that observed neutrino mysteries (solar neutrino deficit, the atmospheric neutrino problem, Los Alamos evidence for neutrino oscillations) can have their roots in mirror world. More details and other references on the subject can be found in semi-popular reviews [21, 22].

Is there any observational evidence for mirror matter? Certainly there are no experimental facts which unavoidably demand mirror matter existence. Otherwise you would know about this form of matter before our conference. But there are impressive amount of facts which can be interpreted as indicating towards the mirror world.

The main difficulty in observing mirror matter is caused by its very weak connection with ordinary matter. These two forms of matter interact predominantly by gravity only. And gravity is very feeble interaction. Nevertheless if some mirror object is massive enough its gravitational effects could be observable. Interestingly one of main problems of modern astrophysics is the presence of huge amount of invisible dark matter in the universe. And the mirror matter is a natural candidate for dark matter [18, 23]. Large clumps of mirror matter will cause gravitational lensing effect on the light from background galaxies. And recent weak microlensing studies [24] had really discovered two such galaxies (or galaxy clusters) almost empty from the luminous matter. Maybe this is the first observation of mirror galaxy [21]. Mirror stars in our galaxy can also produce gravitational microlensing effect on background stars. Such microlensing effects also had been observed and can be interpreted as observations of mirror stars in the Milky Way halo [25].

On smaller scales ordinary and mirror matter are expected to be naturally segregated because they do not have common dissipative interactions [18]. So we expect that systems of the solar system size will have almost definite mirrority. But some small admixture of matter with opposite mirrority is also not excluded and one expects the existence of binary systems like ordinary star with mirror planet or vice versa. Remarkably some extra-solar planets recently discovered have strange properties like being very close to their host stars and therefore may be mirror planets [26, 27]. Even more impressive is recent discovery [28] of floating planets which have no apparent host stars. Instead of being really isolated, which is unexpected in conventional theories of planet formation, these "planetary mass objects" could be ordinary planets orbiting invisible mirror stars [29].

As we see the mirror world model makes at least five predictions about gravitational effects which are really observed:

- the existence of dark matter

- gravitational lensing effects caused by invisible galaxies

- microlensing events due to invisible stars

- strange extrasolar planets

- isolated planets

So this model could be considered as extremely successful. Nevertheless there is no conclusive proof that any of the above listed effects is really some manifestation of mirror world and can not be explained otherwise. Further work is needed to establish unambiguously whether the mirror world really exists. Meanwhile we can speculate about possible mirror solar companion(s) [22, 30].

So far we talked about revealing mirror matter through its gravitational fingerprints. But gravity is not necessarily the only way to connect the two worlds. For neutral particles like Higgs, photon and neutrinos one can imagine ordinary-mirror mixing which is good from the point of modern field theory (that is the mixing turns out to be gauge invariant and renormalizable). The mirror world model with these mixing terms predicts three major effects in particle physics beyond the Standard Model and two of them are really observed! The third one involves Higgs-mirror Higgs mixing which can modify significantly the Higgs scalar properties [17] but we will be able to test this prediction only after the Higgs discovery.

Neutrino-mirror neutrino mixing leads to maximal neutrino-mirror neutrino oscillations no matter how small the Lagrangian mixing parameter is. This maximality of mixing is a quite general consequence of **MP** symmetry and provides a clear experimental signature of this model [19]. It seems that neutrino oscillations (very likely maximal!) are really observed experimentally. But unfortunately the mirror world is again slipping away from our hands: the last experimental data disfavors the pure active-sterile oscillations [32]. But we do not agree that at present a sterile neutrino is excluded by experiment and bet that the sterile neutrino will strike back soon. It seems that the observed neutrino anomalies are more complex phenomena than it was initially thought. Besides active-sterile mixings, neutrinos could have mixings among active (ordinary) species, like flavor mixing in quark sector, and among their mirror (sterile) partners. So we do not expect the two flavor active-sterile neutrino oscillations (which is excluded now) to be the only loophole for sterile neutrinos. But again we have no definite experimental manifestation of the mirror world through neutrino oscillations at present – only indications towards it.

Photon-mirror photon mixing if present will result in a small ordinary electric charge acquired by mirror charged particles. As a result mirror matter will be able to interact with ordinary matter electromagnetically although by much reduced strength. But compared to gravity the electromagnetic interactions are tremendously powerful. So even a very small mixing can lead to interesting observable effects. For example, orthopositronium will mix with mirror orthopositronium and decay into an invisible state [33]. So its decay rate will not coincide with the theoretical prediction [33]. Interestingly such discrepancy is really observed in some experimental measurements and the mirror world may help to resolve this longstanding discrepancy [34]. Note that the mirror world effect on the orthopositronium decays will appear only in vacuum experiments because otherwise the ordinary matter environment will destroy coherence between mirror and ordinary parts of the orthopositronium state vector and suppress the oscillations. Such kind of coherence loss is important also in other phenomena involving photon-mirror photon mixing [35].

The resolution of the orthopositronium lifetime puzzle via mirror world scenario requires relatively large photon-mirror photon mixing parameter [34]. If the mixing parameter is indeed so large an interesting possibility will be opened that the mirror world can lead to the Tunguska-like events and maybe the Tunguska event itself was a manifestation of the mirror world [2]. But this is another story – for details see Foot's talk at this conference [2]. Instead we will speculate now about a possibility that a tiny electromagnetic interaction between the mirror and ordinary atoms will be nevertheless enough to prevent ordinary accretion material near the large mirror body from falling to its center. If the repulsion between ordinary and mirror electron orbitals is enough to overcome gravitational attraction on the surface of mirror body the ordinary dust and other accreted material will stay on the surface

and will form some kind of very fragile and porous crust. As a result the mirror body will become visible and may appear as some strange object for a distant observer. Are there any such objects in the solar system? We speculated earlier [22, 30] that there might be a mirror planet in our solar system that might be found one day. But perhaps an even more interesting possibility is that one has already been found! There are some strange objects observed in the solar system and we list them below. Potentially they could be candidates for a mirror celestial body covered by ordinary crust.

Let us begin with the ninth planet Pluto [36]. Some of its strange properties are [37]:

- highly eccentric orbit

- orbital inclination much higher than the other planets'

- the second most contrasty body in the solar system

- covered with exotic, super-volatile snows of nitrogen, methane and carbon monoxide

There is also some evidence that the Pluto's surface is very porous [38]. Maybe one day NASA can send space ships to Pluto to bring back mirror matter! That could be useful because the mirror matter should have useful industrial applications [2].

Another strange object in the solar system is Saturn's outermost satellite Phoebe. Here are some of its oddities [39]:

- very low albedo, it is as dark as lampblack

- eccentric, retrograde orbit

- high orbital inclination

- anomalously low density of about 0.7 g/cm^3

Of course, rather being a mirror object, phoebe more likely may be a dark carbonaceous captured asteroid formed in the outer solar system as scientists believe. But who knows . . .

Undoubtedly the strangest object in the solar system and maybe the best candidate for mirror object covered by ordinary crust is Saturn's another moon Iapetus [40]. It orbits not in a plane of the other moons. Its density 1.1 g/cm^3 indicates that Iapetus must be composed almost entirely of water ice. Indeed its trailing hemisphere is very bright. But mysteriously the leading hemisphere is completely different – it is as dark as lampblack. See Fig.2 which shows Iapetus as seen by Voyager-1 spacecraft. Standard explanation is that the leading hemisphere is coated by a dust material knocked out of Phoebe by meteor impacts. But in this case meteor impacts on Iapetus dark hemisphere is expected to produce craters with bright floor and none of them is observed. What is observed is just opposite: dark-floored craters in Iapetus' high-albedo hemisphere.

So it is even possible that mirror matter has already been discovered and everybody can look at mirror body in our solar system by telescope. But we feel we are becoming too open-minded here. So it is good time to finish before our brains fall out.
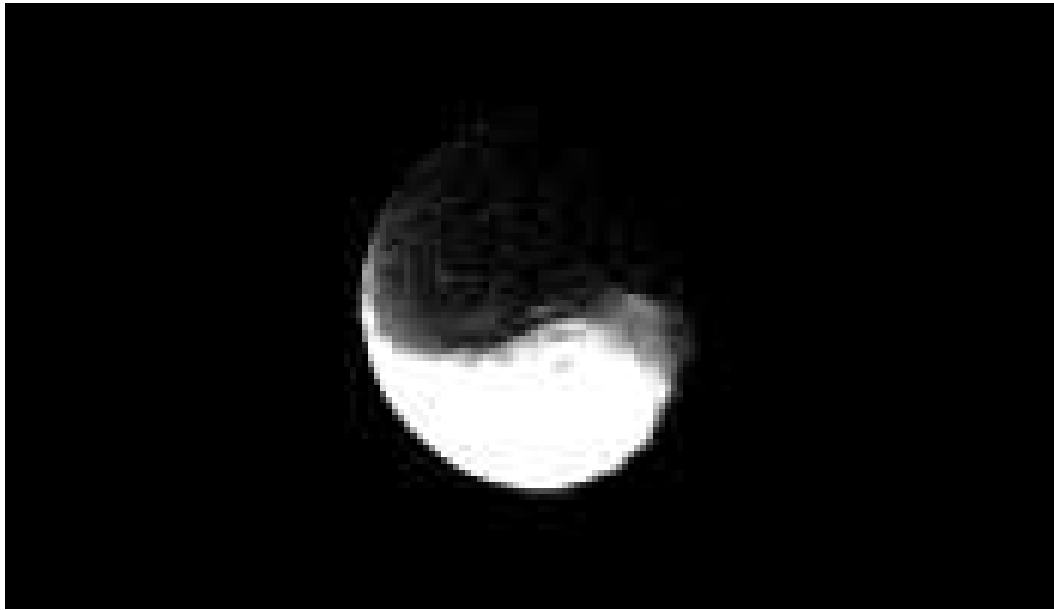
Fig. 2. Iapetus' image taken by Voyager-1 spacecraft

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